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Title: Applications of Intelligent Techniques for Electrical Power Quality Monitoring of Distribution Generation

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ABSTRACT

With the increasing penetration of renewable energy in modern power system, in particular in Distribution system, the monitoring of electric power quality has attracted significant attentions. The DG technologies are based on power electronics technologies, brings power quality disturbances to power system connected with DG. Hence a power quality monitoring system is used to detect and analyzes power quality events.

In the present study, graphical programming of LabVIEW software has been utilized to develop intelligent power quality monitoring system to monitor power quality disturbances (like voltage sag, swell, interruption, frequency variation, etc.) using DAQ Card (inserted in PC). Virtual instrumentation saves the extra cost, time and energy that are incurred while setting up traditional instrumentation systems. The information from power quality monitoring systems can help improve the efficiency of operating the system and the reliability of customer operations. The capabilities and applications for power quality monitors are continually evolving. Also, Islanding detection is a key issue when a DG works in connection with the Smart Grid. So, there is a need of development of an intelligent system based on communication technique to stabilize the DG system during electrical power quality disturbances.

Key words: Power quality monitoring, distributed generation, smart grid, LabVIEW, Islanding, communication.

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1. INTRODUCTION

1.1 POWER QUALITY MONITORING

With the new technology and different software available in the market, the power quality monitoring becomes very important to the utilities and also to the customers. The monitoring system can provide information about the quality of power and the causes of power system disturbances. It can also identify problem conditions throughout the system before they cause widespread customer concerns, equipment malfunctions or equipment failures. In order to improve the electric power quality, the power disturbances should be monitored continuously. The power quality monitoring must be able to detect, localize, estimate and classify the disturbances in power system.

The term power quality refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location on the power system. The power quality problem is defined as "any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment." Power quality disturbances can range from short interruptions to long interruption, magnitude variations and flicker. Recently, the importance of power quality issues has increased due to various reasons.

There are a few factors causing the need to solve and prevent power quality problems so that the customers and utilities will be able to prevent any untoward incident from happening. Those factors are:

- The increased use of power quality sensitive equipment
- The increased use of equipment that generate power quality problems
- The interconnectedness of the power system
- The deregulation of power industries

Hence, developing a new modern monitoring system which integrates the effective measurement, control, communication and supervision of PQ is important. An intelligent PQ monitoring system comprising of both hardware and software are needed in order to provide adequate coverage of the entire system, to understand the causes of these disturbances, to resolve existing problems and to predict future problems.

Power quality monitoring is the process of gathering data about voltages and currents, transporting the data to a useful resource, and processing it into decision-making information. The process of gathering data is usually carried out by continuous measurement of voltage and current over an extended period. The process of analyzing and interpretation has been traditionally performed manually, but recent advances in signal processing and artificial intelligence fields have made it possible to design and implement intelligent systems to automatically analyze and interpret raw data into useful information with minimum human intervention.

PQ Monitoring process consists of following four steps:

1. Data Acquisition: The first step in the process of power quality monitoring comprises of collecting data from various power quality measurement instruments, voltage recorders, monitors, and digital fault recorders. The data is then converted to the PQ data interchange format recommended by the IEEE Standard 1159.3.
2. Characterizing: The formatted data may then be transferred to a data characterizer for identification of the PQ event. The basic characteristics such as rms value of voltage and current, harmonic components and frequency are calculated using various signal processing algorithms.
3. PQ analyzer: The basic characteristics are analyzed and PQ events are detected.
4. Statistical analysis: The PQ trends and events are analyzed in a statistical manner and PQ indices are calculated.

Nowadays most power quality measurement systems are developing from meter or analyzer to monitoring system. The conventional power quality monitoring was consisting of meters and analyzer. The metering group measures the instantaneous values of the measuring point such as rms values. The Analyzer group measures periodically changing values and mainly performs the harmonic analysis, waveform capture and event detection. The power quality monitor capture steady state parameters but also power quality events. Recently PQ monitoring devices are developing into monitoring system that continuously measures the PQ of a point and analysis the trends of power quality. Power quality measurement systems have many variations in their structure, price and function.

1.2 DISTRIBUTED GENERATION

The recent developments in the technologies have made tremendous gain in the performance of small distributed generations which are much cost effective. Also a deep concern has been developed regarding the reliability and quality of electric power. DG is used to provide electricity service at a high level of reliability and power quality than conventional grid power system. DG is capable of protecting sensitive loads from momentary voltage variations. It can provide uninterruptible power supply to ride through any sort of outage until primary or secondary power is restored. It is environmental friendly, promotes renewable energy resources, improves system power factor, and power quality in terms of node voltage drop and power loss reduction.

The DG technologies are based on power electronics technologies, so a many power electronic devices are applied to the DG. This brings power quality disturbances to power system connected with DG. There are a large number of common power quality disturbances such as voltage deviation and frequency deviation, three phase unbalance, harmonics and inter-harmonics, voltage fluctuations, short duration voltage variations and electromagnetic transients. From a power quality perspective, the presence of distributed generation technology will definitely influence the transient voltage variation and harmonic distortion of the system voltage during connection and disconnection.

1.3 SMART GRID

The integration of distributed renewable energy generators has great impacts on the operation of the grid and calls for a new grid infrastructure which is called smart grid which is a combination of different existing standards, information, communication, and power technology. It includes an intelligent monitoring system that keeps track of all electricity flowing on the system. This will have a profound impact on future electricity technology, which allows information and communication technologies (ICT) and advanced power electronic devices to be installed and embedded throughout the networks.

The smart grid is high complex combination and integration of multiple analog and digital technologies and systems. Communication is the soul of a smart grid. A modern grid has intelligent electronic devices (IEDs) throughout the transmission and distribution infrastructure and facilitates constant exchange of data through control signals between these points and the utility operators.

1.4 ISLANDING

A very important requirement which is mandatory to DGs is their ability to detect islanding conditions. Islanding is the generic term used to describe a scenario where a section of a transmission or distribution network, which contains distributed generation, is separated from the main transmission or distribution grid. Subsequent to this separation, the DG continues (or is restarted) to power the loads trapped within the island. According to IEEE Standard 1547, Islanding is defined as the condition in which a portion of an electric power system is energized solely and separated from the rest of the electric power system. Among the causes of system islanding, malfunctions of protective equipments and multiple tripping of distribution lines triggered by natural disasters are the most common.

From operational point of view, islanding may be intentional and unintentional In the event of unintentional islanding, utility network should be design in such a way that it must be able to detect the phenomena and isolate it from remainder of the grid immediately. Normally, unintentional islanding occurs because of natural disaster or abrupt system fault by switching operation of protective devices. The non detection of islanding phenomena may adversely affect the utility networks. It is not only harmful to the life of operating staff but also uneconomical to electric power distribution system. It reduces the useful life of system to considerable extent. The quality of power is deteriorated and failure of customer's electric appliances enhanced.

Islanding Detection Techniques

There are many proposed techniques for detection of an island. These techniques can be broadly classified into remote and local techniques. Local techniques can be further classified into active and passive techniques. Remote techniques for detection of islands are based on communication between the utility and the DGs. Although these techniques may have better reliability than local techniques, they are expensive to implement.

Another category of methods for detecting islanding is based on communication between DG and utility grid. There are three main methods using communication are:

i. PLC: Power line used as carrier for communication between the DG and utility grid. A continuous signal is transmitted by utility network via the power line. A receiver is necessary to be connected to the DG for detecting the loss of this signal and hence determining islanding conditions.

ii. SCADA based method: In this method, the voltage sensors are placed at the location where DG is connected and integration of those sensors in the SCADA system for monitoring and alarming the DG system to disconnect in case of islanding. Using communication standards such as IEC 61850 and its extensions for DGs, a SCADA application can be implemented to communicate to all DGs in a distribution grid and inform them about islanding conditions. GOOSE massages are one of the unique features provided by IEC 61850 that allow fast messages between different IEDs in a peer to peer format. This feature can be extremely helpful for improving the security of the overall power system.

iii. Transfer Trip Method: The basic idea of transfer trip scheme is to monitor the status of all the circuit breakers and reclosers that could island a distribution system. Supervisory Control and Data Acquisition (SCADA) systems can be used for that. The principle of the supervisory control and data acquisition (SCADA) to detect unintentional islanding is to monitor states of entire distribution system such as voltage, frequency and other characteristics. This information is then sent through communication links to a central station. After the utility is disconnected, if the parameter (voltage or frequency) can still be detected from the disconnected area, then the occurrence of islanding is hereby detected. If the system is properly instrumented and controlled, this method is highly effective to detect unintentional islanding and the NDZ is eliminated. The weaknesses of the transfer trip system are better related to larger system complexity cost and control. As a system grows in complexity, the transfer trip scheme may also become obsolete, and need relocation or updating.

2. LITERATURE REVIW

1.1 REVIEW OF EXISTING POWER QUALITY MONITORING SYSTEM

There are various International Standards for power quality monitoring. Some of them are IEEE 1159-1995 and IEC 61000-4-30. The standard IEEE 1159-1995 defines and describes power quality phenomena, their classification, and effect of various power quality disturbances on equipment. It also describes monitoring objectives, measuring instruments used for data collection, monitoring instruments, and analysis and interpretation of various events.

The standard IEC 61000-4-30 defines the methods for measurement and interpretation of results for power quality parameters. Measurement methods are described for each relevant type of parameter in terms of that will make it possible to obtain reliable, repeatable and comparable results. The power quality parameters considered in this standard are: power frequency, magnitude of the supply voltage, flicker, supply voltage dips and swells, voltage interruptions, transient voltages, supply voltage unbalance, voltage and current harmonics and inter-harmonics, mains signaling on the supply voltage, and rapid voltage changes.

The Standard IEEE 1547 governs the interconnecting of distributed resources (DR) with electric power system. The criteria and requirements specified in the standard are applicable to all DR technologies. IEC 61850 is a standard recommended by IEC for communication within the substation. The communication services and data models are defined in section 61850-7-2 of the standard. GOOSE massages are one of the unique features provided by IEC 61850 that allow fast messages between different IEDs in a peer to peer format. This feature can be extremely helpful for improving the security of the overall power system.

A large numbers of works have been published and implemented describing the development of power quality monitor (PQM) from metering to monitoring. The contribution of some of researchers has been highlighted as follow

Mark McGranaghan discussed system approach to intelligent power quality monitoring, various applications of power quality monitoring, and monitoring requirements for different types of power quality variations. Alex McEachern highlighted necessary characteristics

about the ideal intelligent PQM system and future of PQM system. It also highlights the history of intelligent power quality monitoring and some unsuccessful PQM products.

Rong-Ceng Leou et al. proposed designs a database management system to store the data of power quality and a friendly man-machine interface. Dong-Jun Won proposed power quality monitoring system with central processing scheme. This system can be easily upgraded because PC technology is rapidly developing. This PQM is more flexible, reliable, fast and economical. The only disadvantage of this system is that its communication burden is relatively heavy. L.F Auler et al., presented new protocols for monitoring power quality in an industrial environment by means of Ethernet network to perform a real time waveform monitoring, allowing an oscilloscope like analysis. Batista presented the development of a low cost digital system useful for power quality monitoring using a data acquisition board and LabVIEW. The developed monitoring system is flexible, presents a user-friendly interface and a large data storage capacity. The reports can be accessed through Internet.

M.E. Monteiro et al. presented PQM system based on the Internet. The security aspects of the system were not pointed out. Giovanni Bucci et al. developed a digital measurement station to monitor power quality. Its main features are remote data transmission capability and reduced cost. W.L.Tse and W.L. Chan presented a novel voltage monitoring system based on a compact microprocessor module. It provides a low-cost and flexible solution for monitoring the power quality of electricity supply.

S. Chen established the need to encourage interoperability between power quality instruments from different vendors. It discusses the frequent problem of incompatibility between equipment that results from the inherent inflexibilities in existing designs. Abdullah and Sha'ameri proposed real time PQM system based on DSP Processor to monitor and analysis power line waveforms using Periodogram and Spectrogram signal analysis techniques. The analysis results shows that the spectrogram analysis gives better characterization of power quality problems compared to power spectrum.

Hongliang, Zhou proposed a cost-effective scheme to realize real time PQM using Motorola processor DSP56002 based on GPRS for remote distribution system. It has the merit of always on-line, flexible structure and low cost. David Chang et al. designed a novel Power Quality (PQ) monitoring and report-back system to achieve the goal of real-time PQ monitoring and recording. Dong-Jun Won proposed an improved realization of a distributed

monitoring scheme for PQ diagnosis and developed a systematic algorithm to locate the power-quality (PQ) event source in the distributed monitoring system. The proposed algorithm can replace the expert's analysis on the PQ event source with an automated computer program.

Bassidhar E. Kushare et al. had implemented a web based real time PQM system. This system allows user to access the power quality information and provides auto email notification of the custom power quality report to specified users. Xi Luo, et al. developed an auto monitoring system for distributed generation based on virtual instrument to trace voltage deviation three phase unbalance, and electromagnetic transient. The system consists of hardware and software components.

Hongjiang He et al. proposed the PQM based on Digital Signal Processing. In this system TMS320F2812 is a main controlling chip which makes full use of its powerful data processing ability. Lin Tian and Zhao Xia have implemented the PQM system which collects data automatically through Ethernet network. The power quality can be analysis with the help of GIS (Geographical Information System).

Qiu Tang et al., designed a multifunctional power quality monitoring system and implemented in LabVIEW environment. Yang Huping and Bi Zhipeng designed the power quality parameters monitoring system based on virtual instruments. Renato Alves et al., developed an Electric Power Quality Monitor. The hardware of the Monitor is constituted by four current sensors based on, four voltage sensors, a signal conditioning board and a computer. The software of the Monitor consists of several applications, and it is based on LabVIEW.

Phang Yoke Yin and M. V. Chilukuri developed a computer based data acquisition system that provides real-time monitoring of voltage and current at the customer's point of common coupling (PCC). Any power quality disturbances sustained by the user throughout the monitoring period were detected and recorded on remote PC. Post acquisition analysis was performed on the collected data.

Vinay Dwivedi and Dheerendra Singh have developed successfully a power quality monitoring (PQM) system on a Virtual Instrument using LabVIEW. Yong Tang et al., used the combination of DSP and MCU in power quality on-line monitoring system to store, display, count and analyze the collected data of voltage and current from each terminal, and

communicate with supervisory computer through GPRS communication module to realize power quality monitoring in the grid. Hence it is clear the power quality monitoring expanded from a means to investigate customer complaints to an integral part of power system performance assessments.

1.2 REVIEW OF EXISTING ISLANDING DETECTION TECHNIQUES

The main philosophy of detecting an islanding situation is to monitor the DG output parameters and system parameters and decide whether or not an islanding situation has occurred from change in these parameters. A number of techniques have been presented in literature to monitor the islanding condition.

A comprehensive survey on different islanding detection methods has been documented by M. Ropp and W. Bower. Islanding detection algorithm, based on the proportional power spectral density is proposed by Jun Yin, Liuchen Chang, C. Diduch. This Algorithm is robust, against the load variations and has fast response during the occurrence of islanding process. However, due to mass load switching and fault, frequency variations may occur. This inevitably will cause large proportional power spectral density in low frequency band of grid periods, leading to a nuisance trip for islanding.

Sung II Jang and Kwang-Ho Kim have presented an islanding detection method for DG using voltage unbalance method and total harmonic distortion of current. The proposed algorithm is applicable only for single DG case. An intelligent based approach to islanding detection in DG have been developed by Khalil EI-Arroudi et al., which can be implemented successfully with high degree of accuracy for multi-DG system and has the ability to optimize the threshold values for various system parameters. However, much computational work is involved in the implementation of technique which may prolong the operating time and adversely affect the results.

A hybrid islanding detection technique has been developed by Vivek Menon and M.Hashem Nehrir, in which power flow and voltage unbalance detection techniques are combined to detect the islanding phenomena. The disadvantage of this method lies in the inaccurate selection of frequency set point for power flow in the system. No proper criterion has been developed to select the frequency set point. According to the information gathered from literature review, none of the islanding detection methods is perfect.

3. DESCRIPTION OF BROAD AREA/TOPIC

Intelligent Electrical Power Quality Monitoring System

Modem high-technology industrial facilities require a very high quality of power. At the occurrence of a power quality (PQ) event, these industries are exposed to millions of dollars in financial losses due to equipment malfunctioning, shutdown, and loss of material as scrap. Most of today's high tech facilities have integrated PQ monitoring systems with their facility and process maintenance/control system. The monitoring instrumentation used is usually state-of-art and capable of fast and accurate measurements. These instruments are commonly networked, and communicate to a centralized computer acting as a communication server. The development of an intelligent system requires many approaches such as digital signal processing and rule based techniques along with data mining. Many advanced power quality monitoring systems are equipped with either offline or on-line intelligent systems to evaluate disturbances and system conditions so as to make conclusions about the course of the problem or even predict problems before they occurs. In the present study, graphical programming of LabVIEW software has been utilized to develop power quality analyzer and also to monitor power quality disturbances (like voltage sag, swell, interruption, frequency variation, etc.) using DAQ Card (inserted in PC).

The main philosophy of detecting an islanding situation is to monitor the DG output parameters (e.g. voltage, frequency, power) and/or system parameters and decide whether or not an islanding situation has occurred from change in these parameters. The message regarding islanding can be communicated using appropriate/suitable techniques.

4. OBJECTIVE OF THE STUDY/PROBLEM IDENTIFICATION

Developing a new modern monitoring system which integrates the effective measurement, control, communication and supervision of PQ is important. An intelligent PQ monitoring system comprising of both hardware and software are needed in order to provide adequate coverage of the entire system, to understand the causes of these disturbances, to resolve existing problems and to predict future problems.

The main objectives of thesis are:

- Simulation of Electric Power Quality events.
- Experimental verification of the above with a suitable hardware set up for generating power quality events.
- Detection and classification of Electric Power Quality events.
- Development of Intelligent system for Power Quality Monitoring.
- Analysis of the data using Lab View.
- Development of Smart Grid applications to DG.
- Development of suitable Communication topology for close before open technique of islanding detection.

5. METHODOLOGY TO BE ADOPTED

Different virtual instruments were implemented using the NI LabVIEW graphical programming language. The simulations Vis are used to generate voltage waveform. The interfacing devices used to connect the software and hardware is through serial communication.

1. Data collection/ generation
2. LabVIEW /MATLAB
3. Suitable communication systems/protocols for data transfer.

6. PROPOSED/EXPECTED OUTCOME OF THE RESEARCH

The work will be carried out along the following three lines:

1. The understanding of the phenomena captured by power quality monitors.
2. The development of an intelligent power quality monitoring system for automatic processing of measurements and event classification.
3. Communication of signal/message/data using suitable method during minimum time for detection of islanding (smart grid application)

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